Electrical Engineering

Electrical & Electronic Measurements

Comprehensive Theory

with **Solved Examples** and **Practice Questions**

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Electrical & Electronic Measurements

First Edition : 2015
Second Edition : 2016
Third Edition : 2017
Fourth Edition : 2018

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CHAPTER 1

Introduction

1.1 Measurements and it's Significance

The measurement of a given quantity is essentially an act or the result of comparison between the quantity (whose magnitude is unknown) and a predefined standard. Measurement is the process by which one can convert physical parameters to meaningful numbers. The measuring process is one in which the property of an object or system under consideration is compared to an accepted standard unit, a standard defined for that particular property. For the result of the measurement to be meaningful, the standard used for comparison purposes must be accurately defined and should be commonly accepted. Also, the apparatus used and the method adopted must be provable. The importance of measurement is simply expressed in the following statement of the famous physicist "Lord Kelvin":

"I often say that when you can measure what you are speaking about and can express it in numbers, you know something about it; when you can't express it in numbers your knowledge is of a meager and unsatisfactory kind."

Method of Measurement

Direct Measurement

- In this method, the measured or the unknown quantity is directly compared against a standard.
- This method of measurement sometimes produces human errors and hence gives inaccurate results.

Indirect Measurement

- This method of measurement is more accurate and more sensitive.
- These are more preferred over direct measurement.

Mechanical, Electrical and Electronic Instruments

Mechanical

- This instruments are used for stable and static conditions:
- They are unable to respond rapidly to measurements of dynamic and transient conditions because of having moving parts that are bulky, heavy are rigid possessing high inertia.

Electrical

Electrical methods of indicating the output of detectors are more rapid than mechanical methods, but they are limited time response.

Electronic

These instruments require use of semiconductor devices. The response time of these instruments are extremely small as a very small inertia of electron is only involved. The sensitivity of these instruments are also very high. Faster response, lower weight, lower power consumption are some of the advantages of an electronic instrument.

1.2 Types of Instruments

Absolute Instruments

These instruments give the magnitude of the quantity under measurement in terms of physical constants of the instruments i.e. Tangent Galvanometer, Rayleigh's current balance.

Secondary Instruments

In these type of instruments, the quantity being measured can only be measured by observing the output indicated by the instrument. These instruments are calibrated by comparing with an absolute instrument.

1.3 Deflection and Null Type Instruments

Deflection Type

The deflection of the instrument provides a basis for determining the quantity under measurement i.e. PMMC Ammeter, Electrodynamometer and moving iron instruments. They are less accurate, less sensitive and have faster response.

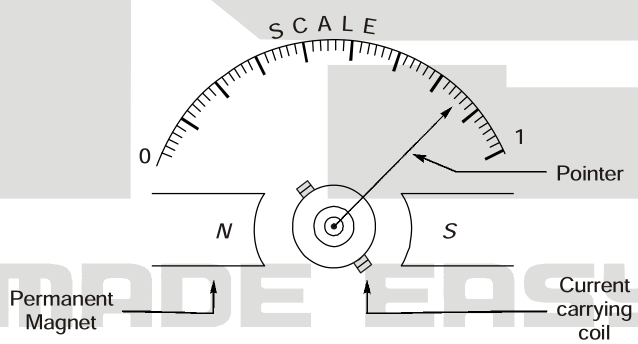


***Figure*-1.1 :** *PMMC (Deflection Type Instrument)*

Null Type Instruments

In null type instruments, a zero or null indication leads to determination of the magnitude of measured quantity. Null type instruments are more accurate, highly sensitive and are less suited for measurements under dynamic conditions than deflection type instruments.

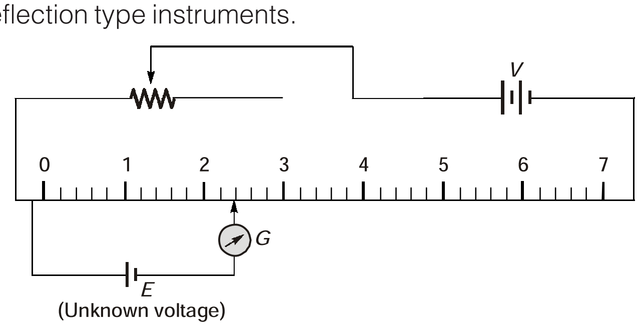


***Figure*-1.2 :** *Null Type Instrument*

Calibration

The calibration of all instruments is important since it affords the opportunity to check the instrument against a known standard and subsequently to find errors and accuracy. Calibration procedures involve a comparison of the particular instrument with a primary standard or, a secondary standard or, an instrument of known accuracy.

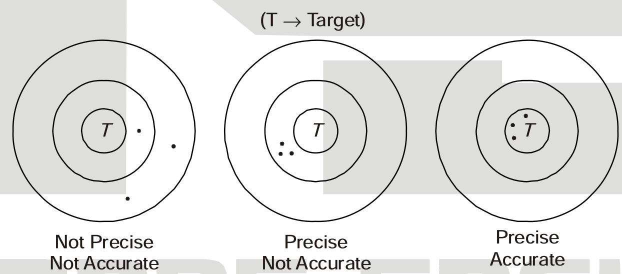
Characteristics of Instrument and Measurement Systems

Accuracy

- It is the closeness with which an instrument reading approaches the true value of the quantity being measured.
- The accuracy can be specified in terms of inaccuracy or limits of error.
- The best way to conceive the idea of accuracy is to specify it in terms of the true value of the quantity being measured.
- The accuracy of a measurement means conformity to truth.

Precision

- It is a measure of the reproducibility of the measurements i.e. given a fixed value of a variable, precision is a measure of the degree to which successive measurements differ from one another.
- The term "Precise" means clearly or sharply defined.
- Precision is used in measurements to describe the consistency or the reproducibility of results.
- Precision instruments are not guaranteed for accuracy.



- Precision depends upon number of significant figures.
- The more is significant figures the more is precision.
- Significant figures convey actual information regarding the magnitude and the measurement precision of a quantity.

Example: 302 A (Number of significant figures = 3)
302.10 V (Number of significant figures = 5)
0.000030 Ω (Number of significant figures = 6)

Example - 1.1 In calculating voltage drop, a current of 4.37 A is recorded in a resistance of 31.27 Ω. Calculate the voltage drop across the resistor to the appropriate number of significant figures.

Solution:

Current, $I = 4.37A$ (3 significant figures)

Resistance, $R = 31.27\Omega$ (4 significant figures)

Voltage drop, $V = IR = 4.37 \times 31.27 = 136.6499$ volt

Since number of significant figures used in multiplication is 3.

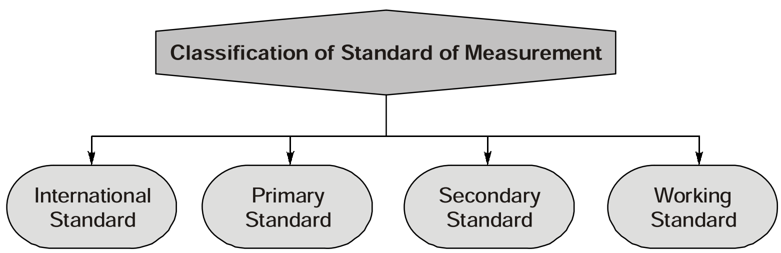
So answer can be written only to a maximum of three significant figures i.e. $V = 137$

1.6 Standard and their Classifications

Standard

A "standard" is a physical representation of a unit of measurement. It is applied to a piece of equipment having a known measure of physical quantity.

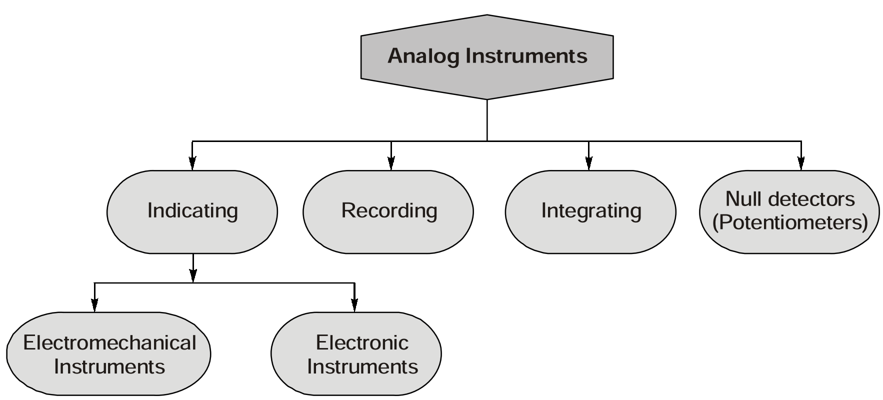
For example, the fundamental unit of mass in the metric system (*SI*) is the **Kilogram**, defined as the mass of the cubic decimeter of water at its temperature of maximum density of 4° C.



Analog Instruments

An analog device is one in which the output or display is a continuous function of time and bears a constant relation to it's input.

Classification of Analog Instruments



Indicating Instruments	Recording Instruments	Integrating Instruments
1. Indicating instruments are those instruments which indicate the magnitude of a quantity being measured	1. Recording instruments give a continous record of the quantity being measured over a specified period.	1. Integrating instruments totalizes events over a specified period of time.
2. It uses a dial and a pointer for measurement of unknown quantity	2. It uses a pen to record the quantity to be measured on a sheet of paper fixed or moving.	2. The output is the product of time and an electrical quantity.
3. **Example:** Voltmeter, Ammeter, Wattmeter, Power factor meter etc.	3. **Example:** Graph, memory etc.	3. **Example:** Energy meter, Ampere hour meter etc.

Quantity of Measurements

Analog instruments are used to measure:

- Current (I)
- Voltage (V)
- Power (P)
- Power factor ($\cos\phi$)
- Frequency (F)
- Energy (w)

Principle of Operation of Analog Instruments

Analog instruments may be classified according to the principle of operations they utilize which are:

(a) Magnetic effect
(b) Heating effect (or Thermal effect)
(c) Electrostatic effect
(d) Electromagnetic effect
(e) Hall effect

(a) Magnetic Effect

When a current carrying conductor is placed in a magnetic field then, a force acts on the conductor which forces the conductor to move.

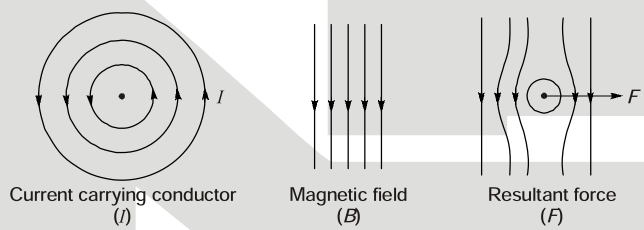


***Figure*-1.6 :** *Current carrying conductor placed in magnetic field (B)*

Force may be attractive or repulsive accordingly the principle is utilized in "attraction type of moving iron instruments" and "repulsion type moving iron instruments".

Examples: Ammeter, Voltmeters, Wattmeters, Integrating meters.

(b) Heating Effect (or Thermal Effect)

The current to be measured is passed through a small element which heats it. The temperature rise is converted to an emf by a thermocouple attached to the element.

The current can be measured and is indication of the rms value of the current flowing through the heater element.

Examples: Ammeters, Voltmeters and Wattmeters.

(c) Electrostatic Effect

When two plates are charged, there is a force exerted between them. This force moves one of the plate. This principle is used in electrostatic type of instruments (Voltmeter).

(d) Electromagnetic Effect

The instruments working on the principle of electromagnetic induction users the principle of electromagnetic effect.

Example: Energy meter, AC Ammeters, Voltmeters and Wattmeters.

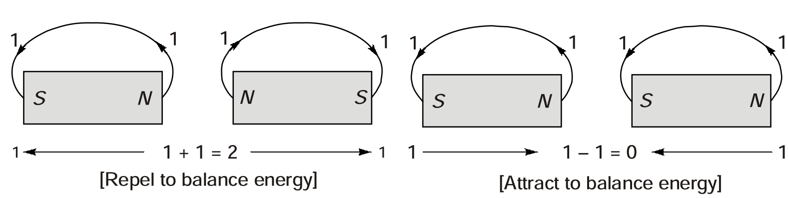


***Figure*-1.7 :** *Attraction and repulsion of two bar magnets placed to each other*

CHAPTER 5

Measurement of Power and Energy

5.1 Introduction

There are many different ways we use energy, many different ways we produce energy and many different consequences environmentally. Power and energy are being measured around us all of the time. We get out electricity bill in Kilowatt hours (kWh), our car performance is measured in horse power, and our light bulbs are rated in watts. To compare these things we need a common set of units.

Energy is required to do work. Work is the exertion of a force over some distance. Energy is the measure of how much work can be done, whether it be heating your house, or driving your car. You transfer energy from one form to another when you do work.

Power is the rate at which you consume energy or do work. Lifting the apple onto the table quickly requires more power than doing it slowly, but the same amount of work is performed.

5.2 Measurement of Power

Measurement of Power in dc Circuit

- For dc circuits power across the load is the product of voltage across it and current flowing through it. Its unit is watt

$$P = VI \text{ Watt}$$

- The power factor of the dc circuit is always unity, hence, only voltmeter and ammeter is sufficient to measure the power in a dc circuit.
- The power indicated by the instrument in a dc circuit is equal to the power consumed by the load plus the power consumed by the instrument nearer to the load terminals as explained for Figure 5.1 (a) and 5.1 (b).

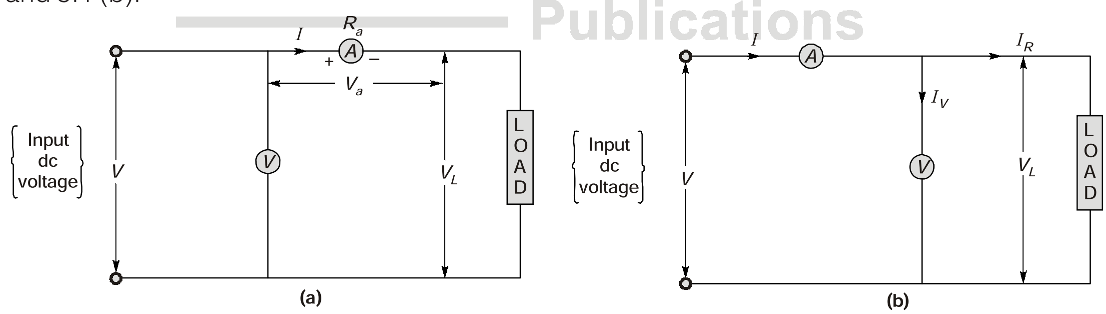


Figure-5.1 Measurement of power in D.C. Circuits

For Figure 5.1 (a)

Power consumed by load $= VI + I^2R_a$

$=$ True Power + Power loss in ammeter

For Figure 5.1 (b)

Power consumed by load $= VI + V^2/R_v$

$=$ True Power + Power loss in voltmeter

Measurement of Power in ac Circuit

In ac circuit, power of the circuit varies due to alternating nature of voltage and current. Thus, we must find the average value of power over a cycle.

Let $v = v_m \sin \omega t$

and $i = I_m \sin (\omega t - \phi)$ ....For lagging load

$\therefore$ Instantaneous power of the circuit (a.c.) is

$$p = v.i. = V_m I_m \sin \omega t. \sin (\omega t - \phi) = \frac{V_m I_m}{2}[\cos \phi - \cos (2\omega t - \phi)]$$

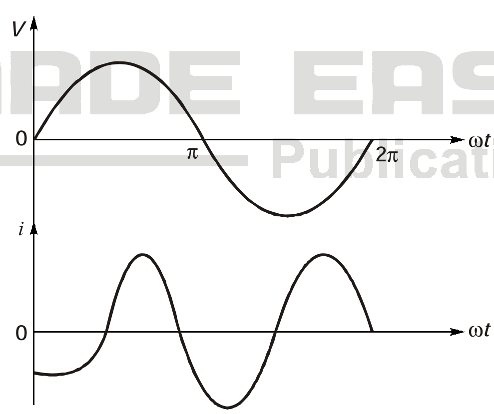
$\therefore$ Average power over a cycle is

$$P_{avg} = \frac{1}{T}\int_0^T p.d(\omega t) = \frac{1}{2}\int_0^{2\pi} \frac{V_m I_m}{2}[\cos\phi - \cos(2\omega t - \phi)]d\omega t$$

or, $$P_{avg} = \frac{V_m I_m}{2}\cos\phi = \frac{V_m}{\sqrt{2}}.\frac{I_m}{\sqrt{2}}\cos\phi$$

Now, $$V_{rms} = V = \frac{V_m}{\sqrt{2}} \quad \text{and} \quad I_{rms} = I = \frac{I_m}{\sqrt{2}}$$

$\therefore$ $$P_{avg} = P = VI \cos \phi$$



As power factor is included in the power measurement of an ac circuit therefore, voltmeter and ammeter alone can't measure the power. Therefore, a wattmeter is required for the measurement of power in ac circuit. We use "Electrodynamometer Wattmeter" for this purpose.

Electrodynamometer Wattmeter

Electrodynamometer wattmeter works on the principle of electrodynamometer its construction and circuit diagram is shown in figure 5.2 (a) and 5.2 (b).

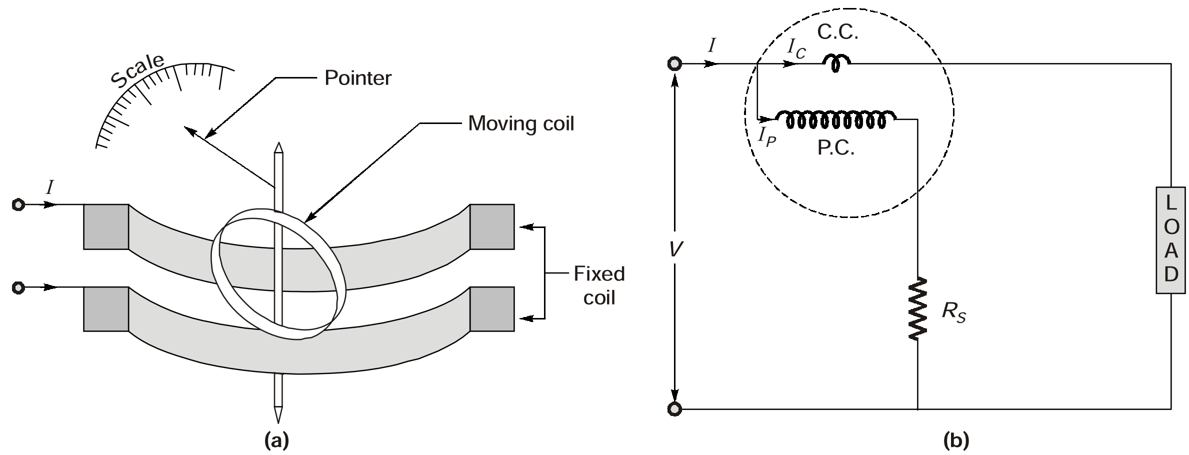


***Figure-5.2 :** (a) Construction (b) Circuit arrangement of an electrodynamometer Wattmeter*

The different parts of an electrodynamometer Wattmeter consists of

(a) Fixed Coil:

- The fixed coils or current coil are connected in series with the load and carry the load current.
- These are also called simply c.c. of the wattmeter.
- The c.c. current lags or leads the supply voltage depending on the load power factor.
- The c.c. are wound with heavy wires and are laminated to avoid eddy current losses.

(b) Moving Coil:

- The moving coil is connected across the load and carries current proportional to voltage. It is also called potential coil or pressure coil.
- A high non-inductive resistance is connected in series with the p.c. to limit the current to a small value. (usually upto 100 mA).
- Spring control is used for the movement.
- Both fixed and moving coil are air-cored.

(c) Damping:

- Air friction damping is used in these Wattmeters.

(d) Control:

- Spring is used which provides the control torque.

(e) Scales and Pointers:

- These Wattmeters uses mirror type scales and knife edge pointers to eliminate parallax errors.

Example - 5.1 In an electro-dynamometer type of wattmeter

(a) the current coil is made fixed
(b) the pressure coil is fixed
(c) any of the two coils i.e. current coil or pressure coil can be made fixed
(b) both the coils should be movable

Solution: (a)

Fixed coil is also called current coil which is fixed and is connected in series with load while moving coil or pressure coil is connected across the load and carries current proportional to voltage.

CHAPTER 6

Cathode Ray Oscilloscope (CRO)

6.1 Basics of CRO (Cathode Ray Oscilloscope)

Cathode ray oscilloscope (CRO) is every popular digital equipment used in laboratory for display, waveform analysis, measurement and other important phenomenon in electrical and electronic circuits. CRO is a linear device where output is proportional to input. It has a *x-y* pattern which display an input signal versus another signal or versus time. The "***time base***" of CRO uses a horizontal input voltage which is a generated ramp voltage. The signal which is to be studied is applied as the vertical input to the CRO.

Basically CRO operate on voltages but, the other parameters like current, strain, pressure, acceleration etc. can also be studied using CRO by converting then into voltages using transducers.

6.2 Advantages of CRO

Following are some of the important advantages of CRO due to which it is widely used now a days:

(*i*) It has *x-y* scale waveform pattern.
(*ii*) Sensitivity is high.
(*iii*) It has high precision.
(*iv*) Frequency and time period can be measured.
(*v*) Phase angle can be measured with the help of CRO.
(*vi*) It can study the quantities from a low frequency (20 Hz) to a very high frequency (upto GHz).
(*vii*) It can display two or more input waveforms simultaneously.
(*viii*) It can be used for high applications (i.e. sampling oscilloscope).
(*xi*) It can measure the voltages like V_m, V_{pp}, V_{rms} and V_{avg}.

Figure (6.1) shows the screen of CRO having *x-y* pattern.

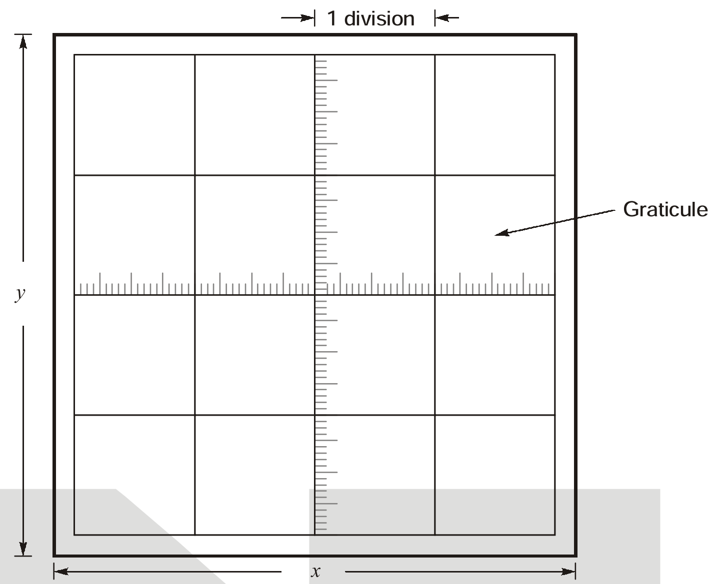


***Figure-6.1 :** CRO screen (x-y pattern scale)*

Example - 6.1 Consider the following statements about a cathode Ray oscilloscope (CRO):
(i) It is an analog equipment used in laboratories.
(ii) It is a linear device.
(iii) It can be used for the measurement of time period, phase angle and power contained in a signal.

Which of the above statements is/are true?
(a) (i) and (iii) only
(b) (iii) only
(c) (ii) only
(d) (i), (ii) and (iii)

***Solution:* (c)**

Example - 6.2 The CRO screen has 12 divisions and each division is set to 5 ms. A voltage of $V = 5\sin(2\pi\ 100t)$ is applied to the CRO then, how many cycles of the waveform can be observed on the screen.
(a) 5 cycles
(b) 12 cycles
(c) 6 cycles
(d) none

***Solution:* (c)**

Given, $v(t) = 5\sin(2\pi \times 100)t$

$\therefore$ $\omega = 00\pi$ rad/s

$\therefore$ Time period, $T = \dfrac{2\pi}{\omega} = \dfrac{2\pi}{200\pi} = \dfrac{1}{100} = 10$ msec

Now, x-scale of CRO = 5 ms and number of divisions = 12

$\therefore$ Total x-scale length = $12 \times 5 = 60$ ms

$\therefore$ Number of cycles of the waveform on the screen = $\dfrac{60}{10} = 6$ cycles

6.3 Cathode Ray Tube (CRT)

Cathode ray tube acts as the heart of the cathode ray oscilloscope (CRO). Figure (6.2) shows the basic construction and parts of cathode ray tube (CRT).

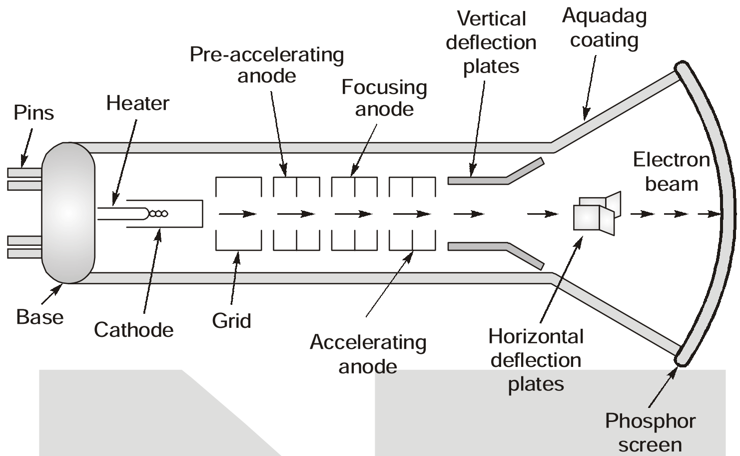


Figure-6.2 : *Construction of a CRT*

Principle of CRT

CRT works on the principle of thermionic emission i.e. emission of electrons from a heated surface.

The various parts of CRT are:

1. Electron Gun
2. Pre-accelerating and accelerating anode
3. Horizontal deflecting plate
4. Vertical deflecting plate
5. Fluorescent screen
6. Glass envelope
7. Aquadag coating

The parts of CRT are described as below:

1. Electron Gun

Electrons are produced from the electron gun which are accelerated to a high velocity. Electrons are emitted from the indirectly heated cathode which has a layer of barium and strontium oxide on the end of the cathode. These electrons pass through a small hole in the control grid, which is a nickel cylinder. The intensity of the electron beam depends upon the number of electrons emitted from the cathode. The grid controls the number of electrons emitted from the cathode and hence the intensity.

2. Pre-accelerating and Accelerating Anode

Pre-accelerating and accelerating anode are applied with a high positive potential which accelerates the electrons emitted from the cathode and passing through the hole. The electron beam is focused by the “focusing anode”. The pre-accelerating and accelerating anodes are connected to a common high positive voltage of around 1500 V. The focusing anode is connected to a voltage of around 500 V.

Focusing of an electron beam can be done by two methods:

(*i*) Electrostatic focusing technique and

(*ii*) Magnetostatic focusing technique.